bodies. Though his publications were comparatively few—rarely more than one or two a year—he wrote well and painstakingly, and many of his papers will remain among our surgical classics. The one surgeon he perhaps admired more than any other was the late Theodore Kocher of Berne, Switzerland, and the two men, in manner and methods surgical, in imagination and ideals, had very much in common. Both of them held their professorships for an unusual number of years—Kocher for forty-five years, Halsted for thirty-three.

Halsted was a man who taught by example rather than precept. He was a safe, fastidious and finished surgeon, by no means a brilliant and showy operator after the style cultivated by many of his contemporaries. He cared nothing for administration, and up to ten years ago at least, his staff never met as a body. He was not a successful teacher of undergraduates. A bed-to-bed ward visit was almost an impossibility for him. If he was interested he would spend an interminable time over a single patient, reviewing the history, taking notes, having sketches made, carrying the problem to the laboratory and perhaps working on it for weeks. Meanwhile his associates and assistants would run his clinic as best they could. In this way his school developed—none of his pupils after his own fashion, to be sure—it would have been impossible to imitate him—all of them, nevertheless, influenced enormously by his attitude toward surgery, and by his operative methods.

His loss to the Johns Hopkins Hospital which he served so faithfully and long, and to which he bequeathed his property, will be irreparable. It will be equally so to his many and devoted disciples. One of his long series of resident-surgeons, who, as others have done, came to know him better after leaving his service, just as many sons learn to know their fathers not until after they have grown up, has in all respect and affection written this inadequate note of appreciation.

''Who knows whether the best of men be known, whether there be not more remarkable persons forgot than any that stand remembered in the known account of time?''

H. C.

EARTH CURRENTS AND MAGNETIC VARIATIONS

Whenever two metallic conductors are buried in the earth and are connected by a wire through a galvanometer a current is found to flow through the galvanometer.

Such a current may be (and sometimes is) caused by a difference of electrolytic action upon, or a difference of temperature of the ground plates, but it is often much stronger than could possibly be produced by such action. It is also regularly the case that the farther apart are the ground connections the greater is their potential difference, and this would not be the case if the currents were due to electrolysis. Since no one has been able to explain these currents by any of the properties of the metallic part of the circuit, it has come to be believed that the currents are flowing in the earth before the two ends of the wire are grounded, and that the wire merely serves as another conducting path between the two earth connections and acts as a shunt for a part of the current. Thus the currents are not regarded as flowing around a circuit consisting partly of the metallic conductor and partly of the earth between its terminals, as they would flow if they were electrolytic or thermo-electric currents, but they are believed to flow in the same direction in both the earth and the metallic conductor.

Since no place has been found, either on land or sea, where these currents will not flow through a long conductor whose ends are earthed, it is believed that there are currents flowing everywhere in the outer layers of the earth's crust and in the sea.

As soon as telegraph lines began to be established it was observed that currents were often set up in these lines when no battery was connected in the circuit. In 1847, a brilliant aurora was observed in Europe and simultaneously with this telegraph lines were greatly disturbed. This led to a careful observation of the diurnal and seasonal variations of the earth currents which were known to be always present in the lines, and to the establishment of a correspondence between these variations and the diurnal and seasonal variations of the magnetic elements of the earth. Since that

time it has been known that the two phenomena are physically related, but there is, as yet, no agreement as to the exact nature of this relation.

In this connection it should be mentioned that two classes of magnetic and electric variations have been observed and are frequently, if not universally, assumed to have the same explanation. It is well known that at times of great sun-spot and auroral disturbances there are also very great and irregular magnetic and earth-current disturbances. It was these abnormal earth-currents which first attracted the attention of physicists, and it is these which have received the most attention from writers on the subject. But in addition to these there is a regular diurnal variation in both the magnetic declination and inclination and in the direction and intensity of the earth-currents. In the literature of terrestrial magnetism, variations of the irregular class are called magnetic *disturbances* while the regular daily and seasonal changes are known as the magnetic *variations*. The relation between the magnetic changes and the earth-current changes seems to be different in the two cases. Thus in the case of the magnetic *disturbances* the corresponding earth-current changes seem to be simultaneous with the magnetic changes, while in the case of the regular diurnal *variations* the magnetic changes seem to lag behind the corresponding earth-current changes by a period which may be as great as two or three hours.

This would seem to suggest that if the regular variations in terrestrial magnetism and earth-currents are related in the sense of cause and effect the irregular magnetic and earth-current disturbances are not so related, but are both apparently due to some external phenomenon which acts simultaneously upon both classes of phenomena. This fact seems not to have been heretofore recognized by writers upon the subject.

The first extensive study of the relation of earth-currents to terrestrial magnetism seems to have been started at the Greenwich Observatory in 1863. Two earth-current lines, one north and south and the other east and west, were established in that year, and continuous records of the earth-currents in these two directions were made. In 1868, Airy, the astronomer royal, published the results of his comparisons of these variations with accompanying magnetic changes. As a result of this comparison, he says:

> I think that on repeatedly examining the agreement of the two systems of curves, it is impossible to avoid the conclusions that the magnetic disturbances are produced by terrestrial galvanic currents below the magnets. . . . At the present time we are unable to say whether the records of the galvanic currents throw any light upon the origin of the diurnal variations in the magnetic elements.

In 1870 Airy published another paper in which he undertook to account for the diurnal magnetic variation, as well as the magnetic disturbances, by earth-currents; but the theoretical curve of magnetic variation which he constructed from earth-current data, while agreeing in general shape with the observed curve of variation, is not coincident with it in time.

Since the work of Airy, the most extensive comparison of the variations in earth-currents and in the magnetic elements of the earth has been made in Germany. In 1883, two underground telegraph lines, one from Berlin to Thorn and the other from Berlin to Dresden, were set apart for the measurement of earth currents, and continuous records of these currents were kept from that time until 1891. The material thus collected was turned over to Professor B. Weinstein, who, with a corps of competent assistants, went over all the records and established for the five years 1884-1888 what he regarded as the constant resultant earth-current in the region between these cities. The diurnal and seasonal variations of this current were then compared with the corresponding variations in the magnetic elements at Vienna and Wilhelmshaven. As a result of this comparison, Weinstein says:

> Personally, I have arrived at the conviction that almost the whole of the changes observed by means of a magnetometer and classed as terrestrial magnetic variations are due to earth-currents which act upon the magnetometer as a galvanometer.

Notwithstanding the very close relation which the curves published by Weinstein show

between the two classes of phenomena, his conclusions as to the immediate relation of the two have not met with universal acceptance. Very few physicists have given any attention to the study of earth-currents in recent times, and most of these have been influenced largely by their theories as to the cause back of both earth-currents and terrestrial magnetism. Some physicists, of whom Balfour Stewart is perhaps the most important, have gone so far as to reach conclusions the reverse of those of Airy and Weinstein, and to attribute the earth currents to the magnetic variations. The fact that the diurnal variations in magnetic direction and intensity which would seem to follow from the changes in the earth-currents regularly lag behind the latter certainly indicates that the current does not immediately act upon the magnetic needle, as in the case of the current and needle of a galvanometer, and as is maintained by Weinstein in the quotation given above; but that the variations of the needle follow changes in the magnetic field of the earth, and that whatever effects are produced upon the needle by earth-currents must be due to changes which these currents have produced in the magnetic field of the earth at that place.

Looked at in this way, a time lag between the changes in current and the magnetic variations growing out of them does not seem improbable. Ewing has shown that in the case of a soft iron wire placed in a magnetizing coil an appreciable time is required for the wire to become fully magnetized. Rayleigh found that with a piece of annealed iron wire only 1.6 mm. in diameter and 17 cm. long the time for complete magnetization in a weak field was from 15 to 20 seconds. Hopkinson, after an extensive study of the rate at which magnetic induction penetrates iron, says:

> Suppose a magnet such as we have here constructed, but of the dimensions of the earth, and that some almighty electrician reversed its currents in the copper coils, the magnetizing force being 2 or 3. It would take some thousands of millions of years before the rate of change of induction at the center of its core would attain a maximum.

It is perhaps not allowable to compare the earth magnetically with a sphere of soft iron, and it is plain that the variation in the magnetic elements at a given place are not due to changes in the whole magnetic field of the earth, as in that case they would occur simultaneously over the whole earth instead of moving around with the sun, as they do, but it does not seem incredible that a change in the direction or magnitude of an earth-current at a given place should require two or three hours to produce its maximum effect upon the magnetic elements at that place. In such a contingency, it seems almost certain that the *rate of change* of the magnetic field at a given time would be proportional to the current intensity at that time. If we assume this to be the case, it is possible to compute from the curve of magnetic variation the direction and relative intensity of the current which is the cause of this magnetic variation.

Thus, when a current flows from north to south below a compass needle it deflects the north end of the needle toward the west. The north-south component of the earth current at Berlin was usually toward the south, and was much stronger in the day time than at night. Its greatest intensity was usually just before noon, and its least intensity in the morning and evening. In Figure 1, the curve A is Weinstein's curve for average diurnal variation in the north-south component of the observed earth-current for the year 1884. Curve B gives the average diurnal variation in the west component of the earth's magnetic field at Vienna for the same period. It will be seen

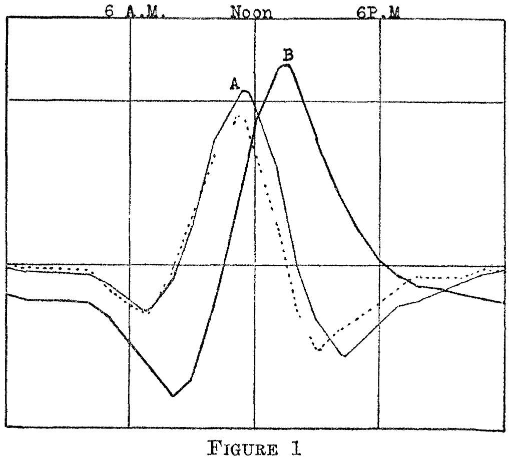

FIGURE 1

that the earth-current toward the south was strongest between eleven o'clock and noon, while the magnetic force toward the west was at its maximum between one and two P.M.

If a curve be drawn showing the *rate of change* of magnetic force throughout the twenty-four hours, we have the dotted curve, which resembles Curve A so closely as to give probability to our assumption that the magnetic deviation is caused by the earth-current, and that the magnetic force is always changing at a rate which is proportional to the intensity of the earth-current.

This relation between the rate of change of the magnetic declination and the intensity of the north-south earth-current has also been observed by Bauer[1] in data taken from the records of *Observatorio Del Ebro,* at Tortosa, Spain, but his conclusion drawn from this relation differs from that given above. Bauer says:

The general conclusion is that the north-south earth-current might be the result of electro-magnetic induction, caused by the fluctuation during the day of the west-east component of the earth's magnetism.

In reaching this conclusion Bauer has overlooked a very elementary and very fundamental law of electromagnetic induction, *viz.,* that a current induced by a change in a magnetic field is in the *opposite direction* to the current which would be required to produce the given change in the magnetic field. If the north-south earth-current and the westward deflection of the magnetic needle are causally related, the magnetic deviation is induced by the current. The contrary can not be true.

In the case of the west-east component of the earth-current conditions are somewhat different. This current weakens the magnetic component toward the north by a very small fraction of its total force, the diurnal range of this weakening being less than one two-thousandth part of the whole, and probably not all of this is attributable directly to the earth current. The resultant effect of the total earth current at a given place is to make the day side of the earth electropositive to the night side, and this condition would, of itself, weaken the north magnetic force on the day side of the earth. That is, a positive charge carried around by the earth's rotation from west to east would set up a north-south magnetic field in the opposite direction to the principal magnetic field of the earth. Such a charge would not, however, affect the east-west magnetic field of the earth.

That the day side of the earth is, on the whole, electropositive to the night side is plainly shown by a series of observations which the present writer has carried on for about three years, and for which he has continuous photographic records for more than two years. That this difference of electric potential on the opposite sides of the earth is due to the electrostatic induction of the negative charge of the sun seems beyond question. A smaller, but still a very definite effect of the moon's induction is also shown by the records.

In Figure 2, Curve A shows the diurnal variation of the earth's potential at Palo Alto for one year, from August, 1920, to July, 1921. Curve B shows the corresponding mean variation of the west-east earth current at Berlin for the year 1884. It is seen that while the earth-current reaches its maximum intensity at between ten and eleven A.M., the electropositive potential of the earth is at its maximum at between one and two P.M. In both cases the time of maximum has a seasonal variation. The same may be said of the variation in the north-south magnetic component of the earth's magnetic field, which for the year 1884 attained its maximum between eleven o'clock and noon at Vienna and Wilhelmshaven, as shown by the dotted curve C. In this case, as in the case of the variation in magnetic

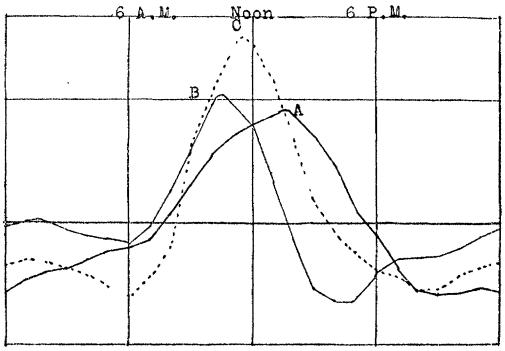

FIGURE 2

[1] *Terr. Mag.,* XXVII, 14 (March-June, 1922).

declination, the change in the earth's magnetic field is in the direction that would be produced by the change in the earth-current intensity and in the electric potential of the earth, hence the current can not be caused by the variation in the magnetic intensity.

Both the earth-currents and the diurnal magnetic variations are in the direction which they would take if they were caused by the electrostatic induction of the sun's negative charge, while the permanent magnetic field of the earth is such as would be caused by the rotation of its own permanent negative charge.

Figure 3 shows the relation between the observed mean diurnal variation of the earth-current in a line about two miles long at Palo Alto and the diurnal variation of the earth's potential for the same three days, as shown by the photographic record. On account of the disturbances in the earth due to trolley lines and other causes, and to possible disturbances in the line, which has been kindly put at my disposal by the Pacific Telephone and Telegraph Company, it is impossible to record the earth-currents photographically with any instrument at my command, and I have been compelled to make all the observations visually. As I have no assistance, I am compelled to make the continuous twenty-four hour runs myself, and for this reason I have at the present time but three such complete records, *viz.*, for June 2, July 18 and August 10, of the present year. The mean

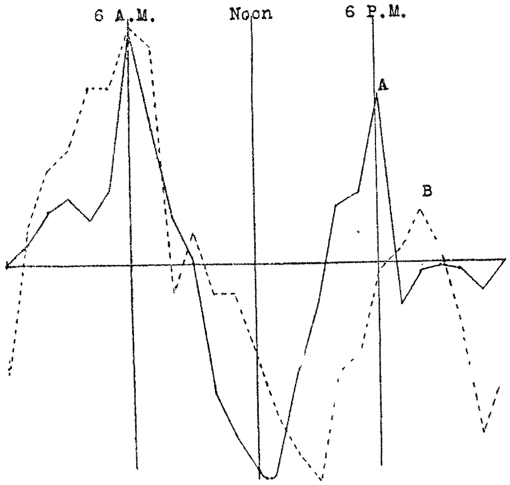

FIGURE 3

diurnal variation for these three days is shown in Curve A in Figure 3, while the mean diurnal variation in earth potential for the same three days is shown by the dotted curve, B. In this curve the signs of the potential are inverted to show better the agreement of the two curves. Both curves show many irregularities which would probably disappear in the mean of a large number of observations, but their similarity in general outline is such as to make it hard to doubt that they are physically related. Their time relation seems to indicate that the positive charge on the day side of the earth is due to the movement of electrons away from the sun.

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RESEARCH AT THE TORTUGAS LABORATORY

THE untimely death of Alfred Goldsborough Mayor and the consequent interruption of the plans of the Tortugas Laboratory of the Carnegie Institution of Washington naturally arouses renewed interest in the work of the laboratory and especially in the investigations now being carried on there. It may therefore be desirable to bring to general notice a brief résumé of the activities of the laboratory and also to point out the purposes of some of the researches now in progress.

The laboratory has been in existence for eighteen years and during that time it has published seventeen large volumes of "Papers from the Tortugas Laboratory," with one or two volumes more in preparation. In addition, a large number of papers, based in whole or in part on work done at the laboratory, were published elsewhere, one of the most important of these being Mayor's own work of three volumes on the Medusæ. (Further discussion of Mayor's researches is found in Davenport's interesting paper in SCIENCE, August 4, 1922). Among the contributors of these papers are many of America's most productive biologists. In estimating the productive activity of the laboratory it is necessary to remember that the laboratory has been open only from eight to fourteen weeks each year and that the greater part of the work has been